BELLCOMM, INC.

SUBJECT: Modified Saturn Launch Vehicles For AAP Earth Orbital Missions Case 600-3

DATE: April 14, 1967

FROM: D. J. Belz

ABSTRACT

One of the major goals of manned space flight immediately following the first four AAP missions will be to provide a modest Earth-orbiting laboratory facility capable of maintaining at least one astronaut in orbit continuously for one year. The total payload-in-orbit required for such a laboratory may, of course, substantially exceed the combined payload capability of the four Saturn I-B vehicles currently planned for production in any given year within the Apollo Applications Program. In addition, it is anticipated that orbital inclinations higher than 28.5° may be required for at least some AAP spacecraft beyond the first four vehicles.

The high anticipated payload requirement for a one-year orbital mission, together with the added demands on launch vehicle performance resulting from orbital inclinations other than 28.5°, provide an incentive for reviewing the capabilities of the Saturn I-B in relation to alternative launch vehicles which might be developed as modifications of existing Saturn vehicles. This memorandum examines a portion of the spectrum of launch vehicle possibilities from the standpoint of anticipated payload and cost.

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MEMORANDUM FOR FILE

1.0 INTRODUCTION

The accomplishment of current plans for the first four AAP flights will result in two manned missions having maximum durations of 28 days and 56 days respectively. AAP 1 through 4 will thus expend four Saturn-IB launch vehicles while providing at most a total of 84 days of manned space operations.

One of the major goals of manned space flight immediately following the first four missions will be to provide a modest Earth-orbiting laboratory facility capable of maintaining at least one astronaut in orbit continuously for one year. The total payload-in-orbit required for such a laboratory may, of course, substantially exceed the combined payload capability of the four Saturn-IB vehicles currently planned for production in any given year within the Apollo Applications Program.

In addition, it is anticipated that orbital inclinations higher than 28.5° may be required for at least some AAP spacecraft beyond the first four vehicles. (An orbital inclination of 49° would permit overflights of virtually the entire United States, excluding Alaska.) Since the optimum orbital inclination for maximizing payload-in-orbit is $\sim$ 28.5° for vehicles launched from Cape Kennedy, higher inclinations will obviously result in reduced payload capabilities.

The high anticipated payload requirement for a one-year orbital mission, together with the added demands on launch vehicle performance resulting from launch azimuths other than due east, provide an incentive for reviewing the capabilities of the Saturn-IB in relation to alternative launch vehicles which might be developed as modifications of existing Saturn vehicles.

This memorandum examines a portion of the spectrum of launch vehicle possibilities from the standpoint of anticipated payload and cost.*

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* Individual classes of vehicles to be discussed below have been the subject of preliminary feasibility studies conducted by Boeing, Chrysler, Douglas, Martin, and North American Aviation Corporations under Contract with MSFC and KSC (References 1 - 16).

2.0 CATEGORIES OF MODIFIED SATURN VEHICLES

Three general types of modified Saturn Vehicles will be discussed. These may be categorized for convenience as:

1. Saturn-IB's augmented by "strap-on" solid rocket motors (SRM's),

2. Two-stage vehicles employing an SIVB upper stage and a new solid-propellant lower stage, and

3. Two-stage vehicles employing two of the three stages of a Saturn-V.

Other ways of modifying Saturn vehicles to obtain payloads between those of S-IB and S-V have been studied in the past. Such modifications have in general been based on one or more of the following component modifications:

1. Increased length of stage propellant tanks to increase propellant capacity.

2. Increased thrust and specific impulse of existing liquid engines by improvement in pump performance, nozzle geometry, and other engine parameters.

3. Use of flourine/oxygen (flox) as an oxidizer to increase thrust and specific impulse.

4. Use of new, higher-thrust liquid engines.

Of these, only increases in stage length are incorporated into configurations to be discussed below and there only for a few of the "strap-on solid" vehicle classes. Performance increases have, however, been achieved in existing liquid engines, e.g., the increase in rated thrust of the J-2 engine from 200,000 lb. to 205,000 lb.; more extensive increases may range from such "evolutionary" improvement to changes that, in a sense, constitute the development of a new engine. Calculated payload increases, e.g., 25% to 40% in low Earth orbit, have been estimated for a Saturn-IB using flox in the first stage;* the toxicity of flourine has, however, generated controversy concerning (a) the feasibility of safely handling large quantities of flourine on the ground and (b) the hazards associated with atmospheric contamination resulting from destruction of a "floxed" vehicle stage during an aborted launch.

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* Reference 17

3.0 MODIFIED SATURN-IB VEHICLES EMPLOYING STRAP-ON SRM'S

Five vehicle classes - designated S-IB 11.5, 11.5A, 11.7A, 13.7, and 14 - will be considered. Configuration descriptions, payload performance, and cost estimates are based on References 1 - 6.

3.1 DESCRIPTION OF VEHICLE CLASSES

Configuration 11.5 consists of a baseline S-IB launch vehicle ("SA-213") modified by the addition of four 120" diameter solid rocket motors (Titan IIIC) of five segments each. The SRM's are attached to the outriggers of the thrust structure at the base of the S-IB stage and to the spider beam at the top of the stage. The four SRM's in this configuration are ignited on the launch pad, while the eight H-1 engines of the S-IB stage are ignited at altitude.* A modified astrionics system is required to: guide the thrust vector control (TVC) system of the SRM's; ignite the H-1 engines; terminate SRM thrust; separate spent SRM's from the S-IB stage; and to provide those functions normally performed by the Instrument Unit (IU) of the baseline vehicle. Flight profiles are such that maximum dynamic pressure on the vehicle is encountered prior to ignition of the H-1 engines. Helium for pressurization of lox tanks in the S-IB stage during engine ignition (47 psia for two second duration) is provided by the launch facility for an S-IB vehicle; ignition of the S-IB stage at altitude, therefore, requires an on-board lox pressurization system (100 lb. additional weight). During boost by "stage zero", the H-1 engines must be restrained from swiveling since they will not be under active control prior to ignition unless modified. Additional structural loads to the "core" vehicle imposed by the SRM's can be accommodated by increasing the skin and bulkhead thicknesses where required.

The 11.5A configuration consists of the baseline S-IB vehicle plus four 120" diameter SRM's of five segments each as in 11.5, plus a dummy segment to facilitate attachment to the first-stage spider beam. Here, however, both the SRM's and four H-1 engines are ignited on the pad while the remaining four H-1 engines are ignited at altitude. In addition, a 20 foot extension in the length of the S-IB stage is assumed for increased propellant capacity.

Configuration 11.7A employs the baseline S-IB vehicle plus four seven-segment, 120" diameter solid rocket motors. For this vehicle as well as 13.7, described below, the use of seven segment SRM's coupled with a requirement to efficiently tie into the S-IB spider beam causes the SRM nozzle exit-planes to protrude 36.67" below the bottom of the H-1 engine nozzles. In

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* The SRM's thus constitute "stage zero" of the launch vehicle, i.e. a stage fired prior to the nominal "first stage" of the S-IB.

11.7A, the ignition sequence is similar to that of 11.5A, i.e., the SRM's and four H-1 engines are ignited on the pad while the remaining four H-1 engines are ignited at altitude. An S-IB tank extension of 20 feet is assumed.

The 13.7 configuration employs two 120" diameter, seven segment SRM's added to the baseline S-IB vehicle which itself is modified by a 20 ft. tank extension. All eight H-1 engines in the first stage as well as the two SRM's are ignited on the pad. (Here the SRM's are used as a boost assist rather than as a zero stage.)

Configuration 14 consists of the baseline vehicle with a boost-assist provided by four Minuteman solid rockets. A tank extension of 10 ft. is assumed as a modification to the baseline vehicle.

The five vehicle classes described above are illustrated in Figure 1. The Apollo payload envelope shown (SLA, CSM, LES) was used in determining performance parameters for each configuration.

Weight changes to the baseline "SA-213" vehicle shown in Table 1 provide one indication of the extent of hardware changes implied by each of the preceding descriptions. The payload performance of each vehicle class is illustrated in Table 2 for direct in-plane injection into circular orbits of 100 NM and 300 NM altitudes. The payloads shown are only representative since they derive from preliminary studies; they are, however, useful for comparative purposes. The maximum payload in a 100 NM circular orbit is shown to be 106,000 lbs. at a reference launch azimuth of 72° (33° inclination); this is 2.83 times the baseline payload, taken here as identical to that of the SA-212 vehicle.

Preliminary studies have indicated the feasibility of developing the alternate configurations under discussion. The selection of one configuration over another would, therefore, depend on cost, performance, and failure mode effects of each vehicle class.

3.2 COST COMPARISON OF MODIFIED S-IB VEHICLES EMPLOYING STRAP-ON SRM's

Costs presented in this section are based on Reference 6. No attempt is made to assess the validity of individual cost estimates; they are, however, employed for comparative purposes to obtain a measure of cost in relation to performance for each vehicle class. The major assumptions and ground rules on which the subsequent discussion is based are as follows:

1. Costs are expressed in 1966 dollars.

2. Earliest hardware go-ahead is January 1, 1968.

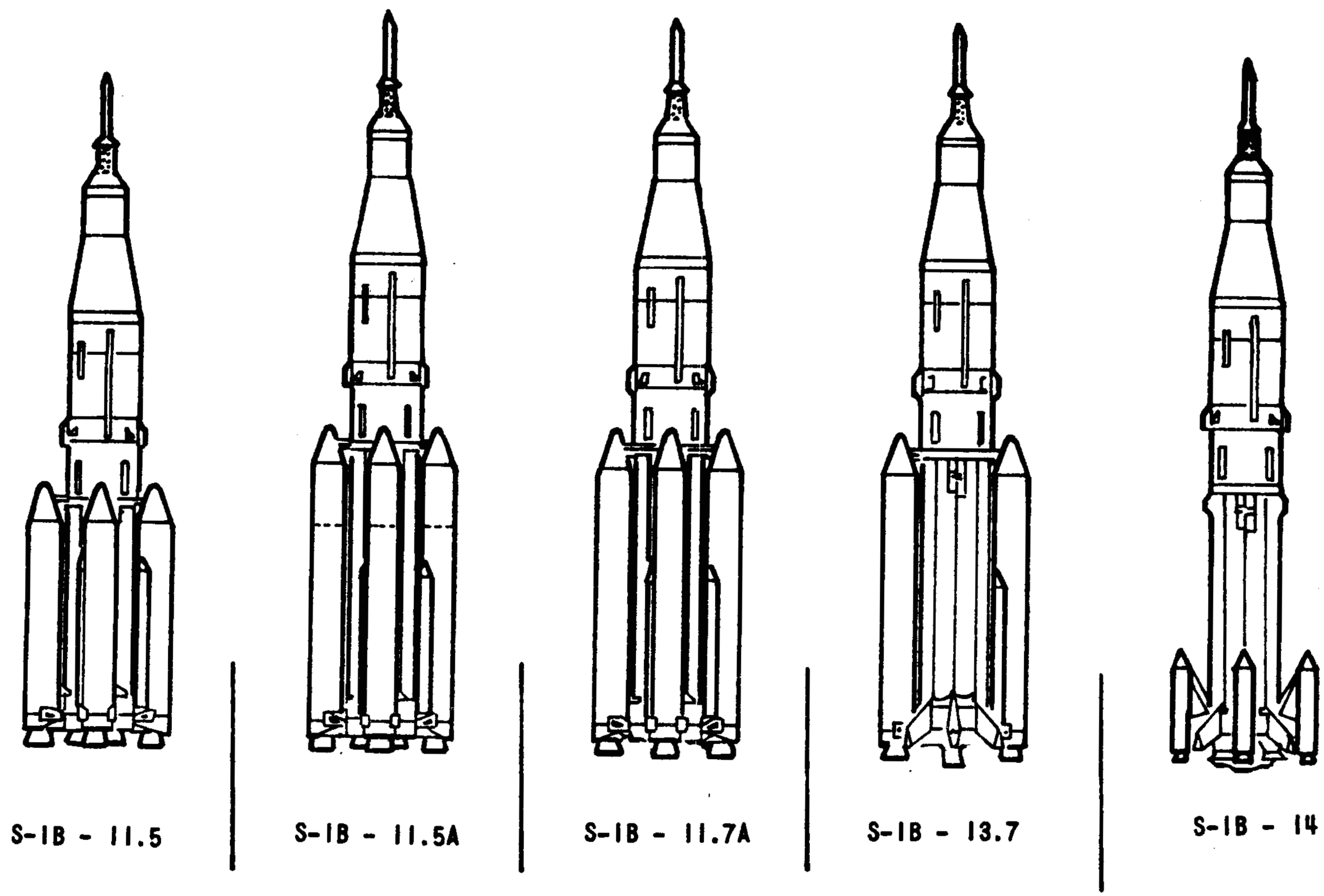

FIGURE 1. MODIFIED SATURN IB VEHICLES EMPLOYING STRAP-ON SOLID ROCKET MOTORS

TABLE I. WEIGHT SUMMARY FOR MODIFIED S-IB LAUNCH VEHICLES AS OF NOVEMBER 1966

ITEM \ VEHICLE DESIGNATION	BASELINE ("SA-213")	MLV-11.5	MLV-11.5A	MLV-11.7A	MLV-13.7	MLV-14
SOLID ROCKET MOTORS (SRM)	----	2,064,504	2,064,504	2,729,252	1,364,626	202,288
SRM INSTALLATION △ WEIGHT	----	4,074	14,560	2,702	1,352	4,283
S-IB STAGE						
DRY	85,292	91,495	102,624	100,971	102,531	98,549
PROPELLANT AND SERVICE ITEMS	896,387	904,508	1,233,018	1,233,158	1,224,014	1,056,543
THRUST BUILD-UP PROPELLANT	14,645	4,300	7,450	7,450	14,645	14,645
FROST	1,000	1,000	1,300	1,300	1,300	1,150
S-IB/S-IVB INTERSTAGE	7,000	7,000	7,000	7,254	7,000	7,000
S-IVB						
WEIGHT AT GROUND IGNITION	256,566	256,566	256,566	256,579	256,566	256,566
IU	3,870	3,870	3,870	3,870	3,870	3,870
LES	8,200	8,200	8,200	8,200	8,200	8,200

NOTE: WEIGHTS SHOWN ABOVE ARE IN POUNDS.
THIS TABLE IS BASED ON DATA PRESENTED IN REFERENCE 1.

TABLE 2. REPRESENTATIVE PAYLOAD ESTIMATES FOR MODIFIED SATURN-IB VEHICLES EMPLOYING STRAP-ON SOLID ROCKET MOTORS

CIRCULAR ORBITAL ALTITUDE	100 N. MILES		300 N. MILES	
ORBITAL INCLINATION	33°	90°	33°	90°
S-IB BASELINE	37,500	30,800	-	17,600
S-IB - 11.5	78,400	63,000	56,000	43,500
S-IB - 11.5A	87,900	70,000	65,000	51,000
S-IB - 11.7A	106,000	82,500	81,500	63,000
S-IB - 13.7	80,500	62,000	61,000	45,500
S-IB - 14	50,600	36,500	33,500	24,000

NOTES: 1. ALL PAYLOADS SHOWN ABOVE ARE IN POUNDS.
2. LAUNCH PROFILE ASSUMED IS DIRECT ASCENT TO CIRCULAR ORBIT.

3. Production rate of six S-IB vehicles per year after SA-212 until modified vehicles are introduced.
4. Two R&D test flights for each class of modified vehicles.
5. Costs of facility modifications, hardware production, ground testing (all-systems tests, dynamic test vehicles) are included.
6. Three months between delivery of last standard S-IB stage and first modified test stage.
7. Operational production rate of modified S-IB's is 6/year for at least five years.
8. Concurrent Saturn-V production rate of 6/yr.
9. MSFC manufacturing and test facilities available as in current Saturn programs.
10. Hardware contract will provide for cost plus an incentive fee of 7%.
11. Pad refurbishment and R&D flight monitoring is included; other post-flight costs are excluded.
12. Overtime allowed to meet schedules.
13. S-IVB stage uses the J-2 engine and standard propellant capacity of 230,000 lbs.
14. All S-IVB stages are static fired at Sacramento Test Center.

Nonrecurring costs incurred for each vehicle class can be conveniently considered in two categories: facility modifications required to support development and operation of a modified S-IB, and development costs directly associated with the vehicle. Nonrecurring facility cost estimates are shown in Table 3; nonrecurring or R&D costs for vehicle development are shown in Table 4. The largest facility modification costs are incurred by vehicles 11.5A and 11.7A ($\$40.45 \times 10^6$ and $\$41.22 \times 10^6$, respectively); the minimum facility modification cost is that of configuration 14, $\$23.01 \times 10^6$. Vehicle 11.7A also requires the largest nonrecurring development cost ($\$207.62 \times 10^6$) while configuration 14 requires the least ($\$153.42 \times 10^6$). Recurring unit costs for operational vehicles shown in Table 5, again indicate the highest cost to be associated with configuration 11.7A ($\$48.59 \times 10^6$) while the lowest is that of vehicle-class 14 ($\$41.39 \times 10^6$).

TABLE 3. NONRECURRING COST OF FACILITIES FOR MODIFIED S-IB VEHICLES EMPLOYING STRAP-ON SRM'S*

VEHICLE	FACILITY	COST ($ x 10^6)			
		FACILITY	GSE	OTHER	TOTAL
11.5	LAUNCH (KSC)	10.68	11.84	0.	22.52
	MSFC DYNAMIC TEST	1.50	0.16	0.69	2.35
	MSFC STATIC TEST	0.	0.51	0.	0.51
	PLANT MODIFICATION	0.47	1.44	0.	1.91
	TOTAL	12.65	13.95	0.69	27.29
11.5A	LAUNCH (KSC)	20.70	13.97	0.	34.67
	MSFC DYNAMIC TEST	1.56	0.16	0.69	2.41
	MSFC STATIC TEST	0.15	0.57	0.	0.72
	PLANT MODIFICATION	1.09	1.56	0.	2.65
	TOTAL	23.50	16.26	0.69	40.45
11.7A	LAUNCH (KSC)	21.28	13.97	0.	35.25
	MSFC DYNAMIC TEST	1.64	0.16	0.69	2.49
	MSFC STATIC TEST	0.15	0.57	0.	0.72
	PLANT MODIFICATION	1.09	1.67	0.	2.76
	TOTAL	24.16	16.37	0.69	41.22
13.7	LAUNCH (KSC)	17.07	10.96	0.	28.03
	MSFC DYNAMIC TEST	1.43	0.16	0.68	2.27
	MSFC STATIC TEST	0.15	0.52	0.	0.67
	PLANT MODIFICATION	1.09	1.48	0.	2.57
	TOTAL	19.74	13.12	0.68	33.54
14	LAUNCH (KSC)	12.17	6.10	0.	18.27
	MSFC DYNAMIC TEST	0.52	0.67	0.69	1.88
	MSFC STATIC TEST	0.14	0.54	0.	0.68
	PLANT MODIFICATION	0.74	1.44	0.	2.18
	TOTAL	13.57	8.75	0.69	23.01

*AFTER TABLE XI-1, REFERENCE 6.

TABLE 4. NONRECURRING DEVELOPMENT COSTS FOR MODIFIED S-IB VEHICLES EMPLOYING STRAP-ON SRM'S**

	MLV-11.5			MLV-11.5A			MLV-11.7A			MLV-13.7			MLV-14		
	DDT & E	R&D VEH(2)	TOTAL	DDT & E	R&D VEH(2)	TOTAL	DDT & E	R&D VEH	TOTAL	DDT & E	R&D VEH	TOTAL	DDT & E	R&D VEH	TOTAL
I. VEHICLE															
INTEGRATION (GFP & SUPPORT)	-	4.80	4.80	-	4.80	4.80	-	4.80	4.80	-	4.80	4.80	-	4.80	4.80
MAINTENANCE OF GSE	-	.80	.80	-	.80	.80	-	.80	.80	-	.80	.80	-	.80	.80
GSE (KSC & OTHER)	4.89	-	4.89	5.92	-	5.92	5.92	-	5.92	4.52	-	4.52	2.25	-	2.25
FACILITIES (KSC & OTHER)	12.18	-	12.18	22.28	-	22.28	22.93	-	22.93	18.50	-	18.50	12.38	-	12.38
OTHER (INCL. TEST & ENGR)	4.19	-	4.19	4.20	-	4.20	4.19	-	4.19	4.21	-	4.21	3.80	-	3.80
SUB TOTAL	21.26	5.60	26.86	32.40	5.60	38.00	33.04	5.60	38.64	27.23	5.60	32.83	18.43	5.60	24.03
II. S-IB STAGE															
STAGE	28.26	20.10	48.36	28.64	21.40	50.04	28.43	21.7	50.13	26.32	21.8	48.12	25.95	21.3	47.25
ENGINES	10.0	4.99	14.99	10.00	4.90	14.90	10.00	4.9	14.90	-	4.80	4.80	-	4.8	4.80
GSE (KSC & OTHERS)	5.09	-	5.09	5.30	-	5.30	5.40	-	5.40	6.68	-	6.68	6.25	-	6.25
FACILITIES (KSC & OTHER)	0.47	-	0.47	1.24	-	1.24	1.24	-	1.24	1.24	-	1.24	0.88	-	0.88
TEST EXPENDABLES	-	.12	.12	-	.14	.14	-	.14	.14	-	.14	.14	-	.12	.12
SUB TOTAL	43.82	25.21	69.03	45.18	26.44	71.62	45.07	26.74	71.81	34.24	26.74	60.98	33.08	26.22	59.30
III. SRM															
STAGE	5.64	15.28	20.92	5.69	15.48	21.17	6.46	17.80	24.26	4.74	9.06	13.80	2.67	2.50	5.17
GSE (KSC & OTHER)	5.72	-	5.72	6.80	-	6.80	6.80	-	6.80	3.70	-	3.70	2.05	-	2.05
FACILITIES (KSC & OTHER)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SUB TOTAL	11.36	15.28	26.64	12.49	15.48	27.97	13.26	17.80	31.06	8.44	9.06	17.50	4.72	2.50	7.22
IV. S-IVB															
STAGE	.42	15.60	16.02	.42	15.60	16.02	3.68	15.60	19.28	4.20	15.60	16.02	.42	15.6	16.02
ENGINES	-	4.60	4.60	-	4.60	4.60	-	4.60	4.60	-	4.60	4.60	-	4.60	4.60
GSE (DAC)	.13	-	.13	.13	-	.13	.13	-	.13	.13	-	.13	.13	-	.13
FACILITIES (DAC)	1.31	-	1.31	1.31	-	1.31	1.31	-	1.31	1.31	-	1.31	1.31	-	1.31
TEST EXPENDABLES	-	.10	.10	-	.10	.10	-	.10	.10	-	.10	.10	-	.10	.10
SUB TOTAL	1.86	20.30	22.16	1.86	20.30	22.16	5.12	20.30	25.42	1.86	20.30	22.16	1.86	20.30	22.16
V. IU		9.4	9.4	-	9.4	9.4	-	9.4	9.4	-	9.4	9.4	-	9.4	9.4
VI. LAUNCH OPERATIONS		31.08	31.08	-	31.29	31.29	-	31.29	31.29	-	31.03	31.03	-	31.31	31.31
TOTAL	78.30	106.87	185.17	91.93	108.51	200.44	96.49	111.13	207.62	71.77	102.13	173.90	58.09	95.33	153.42

*COST INCLUDEDIN APPROPRIATE STAGE.

**REFERENCE 6

TABLE 5. UNIT COSTS OF OPERATIONAL VEHICLES INCLUDING STATIC TEST

ITEM	VEHICLE CLASS				
	11.5	11.5A	11.7A	13.7	14
S-IB STAGE	8.88	9.46	9.51	9.55	9.33
ENGINES	2.50	2.45	2.45	2.40	2.40
S-IVB STAGE	8.06	8.06	8.15	8.06	8.06
ENGINES	2.30	2.30	2.30	2.30	2.30
SRM'S	6.84	6.91	7.96	4.01	1.24
IU	4.70	4.70	4.70	4.70	4.70
VEHICLE INTEGRATION	2.40	2.40	2.40	2.40	2.40
GSE MAINTENANCE	0.40	0.40	0.40	0.40	0.40
OTHER	0.26	0.26	0.26	0.25	0.24
LAUNCH					
BASELINE	10.00	10.00	10.00	10.00	10.00
OPERATIONS	0.16	0.17	0.17	0.13	0.11
GSE REFURBISHMENT & MAINTENANCE	0.18	0.20	0.20	0.15	0.15
FACILITIES REFURBISHMENT & MAINTENANCE	0.01	0.01	0.01	0.01	0.02
EXPENDABLES	0.01	0.08	0.08	0.08	0.04
TOTAL	46.70	47.40	48.59	44.44	41.39

NOTES: 1) COSTS SHOWN ARE IN MILLIONS OF DOLLARS PER VEHICLE.

2) THIS TABLE IS BASED ON TABLE XI-2, REFERENCE 6.

Total costs, including both nonrecurring and recurring items, are shown in Table 6 for a program consisting of from one to six operational vehicles.

Costs considered aside from performance gains are, however, only one measure of comparison. Table 7 presents a "cost/effectiveness" measure for each vehicle class for an operational program varying from one to six vehicles. The cost/effectiveness measure chosen is total cost (nonrecurring plus recurring) for a given number of operational vehicles divided by the total payload capability of the same number of operational vehicles.

Baseline costs for the unmodified S-IB, however, include only recurring costs, the nonrecurring costs being assumed chargeable to prior space program goals. This assumption provides a basis of comparison that inherently favors the standard S-IB. Nevertheless, a program of only 5 operational flights with vehicle 11.7A results in a lower total cost per pound of payload in a low altitude (100 N.Mi.) orbit than the standard S-IB cost. A program of only 3 operational flights with 11.7A results in a lower total cost per pound of payload in a 300 N. Mi. altitude circular polar orbit than with the baseline S-IB. Table 8 shows the number of operational vehicles required to reduce the cost/effective measure below that of a Saturn-IB. Configuration 14, which requires the lowest total cost, is shown to require the most extensive operational program to justify the initial investment.

Therefore, assuming the cost figures employed above to be valid for comparative purposes, the vehicle class SIB 11.7A, in comparison with other modified SIB vehicles employing strap-on solids has been shown to require the least extensive program commitment (in terms of numbers of operational vehicles) to justify its adoption. In addition, the payload capability of an 11.7A vehicle is greater than that of a single vehicle of any of the alternative configurations discussed in this section.

4.0 SOLID-BOOSTED SIVB LAUNCH VEHICLES

This section discusses candidate solid-boosted S-IVB configurations using clustered 120" SRM's, clustered 156" SRM's or a single 260" diameter solid rocket motor. Performance and cost data on these vehicles are based on studies conducted by Douglas Aircraft Company under Contract NAS 8-20242 (References 9, 10).

TABLE 6. TOTAL COSTS FOR ONE TO SIX OPERATIONAL MODIFIED S-IB LAUNCH VEHICLES

VEHICLE CLASS	NONRECURRING COSTS		RECURRING COST PER OPERATIONAL VEHICLE	TOTAL COST FOR X OPERATIONAL VEHICLES					
	FACILITIES	R&D		X=1	X=2	X=3	X=4	X=5	X=6
BASELINE S-IB	0.	0.	38.00	38.00	76.00	114.	152.	190.00	228.00
11.5	27.29	185.17	46.70	259.16	305.86	352.56	399.26	445.96	492.66
11.5A	40.45	200.44	47.40	288.29	335.69	383.09	430.49	477.89	525.29
11.7A	41.22	207.62	48.59	297.43	346.02	394.61	443.20	491.79	540.38
13.7	33.54	173.90	44.44	251.88	296.32	340.76	385.20	429.64	474.08
14	23.01	153.42	41.39	217.82	259.21	300.60	341.99	383.38	424.77

NOTE: ALL COSTS SHOWN ARE IN MILLIONS OF DOLLARS.

TABLE 7. COST/EFFECTIVENESS OF MODIFIED S-IB VEHICLES EMPLOYING STRAP-ON SRM'S

VEHICLE CLASS	CIRCULAR ORBITAL PARAMETERS		TOTAL COST OF X OPERATIONAL VEHICLES ÷ TOTAL PAYLOAD OF X VEHICLES					
	ALTITUDE (N. MILES)	INCLINATION (°)	X = 1	X = 2	X = 3	X = 4	X = 5	X = 6
S-IB BASELINE	100.	33	1000.	1000.	1000.	1000.	1000.	1000.
		90	1200.	1200.	1200.	1200.	1200.	1200.
	300.	33	NOT AVAILABLE FROM REFERENCES CITED.					
		90.	2200.	2200.	2200.	2200.	2200.	2200.
S-IB 11.5	100.	33	3300.	1950.	1500.	1300.	1100.	1050.
		90	4100.	2400.	1900.	1600.	1400.	1300.
	300.	33	4600.	2700.	2100.	1800.	1600.	1450
		90	6000.	3500.	2700.	2300.	2050.	1900.
S-IB 11.5A	100.	33	3300.	1900.	1450.	1200.	1100.	996.
		90	4100.	2400.	1800.	1500.	1400.	1250.
	300.	33	4450	2600.	2000	1650.	1500.	1350.
		90	5650.	3300.	2500.	2100.	1900.	1700.
S-IB 11.7A	100.	33	2800.	1600.	1200.	1050.	930	850.
		90	3600.	2100.	1600.	1300.	1200.	1100.
	300.	33	3650.	2100.	1600.	1360.	1200.	1100.
		90	4700.	2750.	2100.	1750	1550.	1450.
S-IB 13.7	100.	33	3100.	1800.	1400.	1200.	1100.	980.
		90	4100.	2400.	1850	1550.	1400.	1300.
	300.	33	4150.	2400.	1850.	1600.	1400.	1300.
		90	5550.	3250.	2500.	2100.	1900.	1750.
S-IB 14.	100.	33	4300.	2600.	2000.	1700.	1500.	1400.
		90	6000.	3550.	2700.	2300.	2100.	1900.
	300.	33	6500.	3900.	3000.	2550.	2300.	2100.
		90	9100.	5400.	4200.	3550.	3200.	2950.

NOTE: COST/EFFECTIVENESS UNITS ABOVE ARE $/LB.

TABLE 8. NUMBER OF OPERATIONAL MODIFIED S-IB VEHICLES FOR LOWER OR EQUAL COST/EFFECTIVENESS RATIO THAN BASELINE S-IB

CIRCULAR ORBITAL ALTITUDE	100 N. MILES		300 N. MILES
ORBITAL INCLINATION	33°	90°	90°
S-IB - 11.5	7	7	5
S-IB - 11.5A	6	7	4
S-IB - 11.7A	5	5	3
S-IB - 13.7	6	7	4
S-IB - 14	19	73	15

Three configurations will be considered. Each is a two stage vehicle employing an S-IVB* as the second stage. An Instrument Unit (IU) is provided above the S-IVB stage in each case. The primary configuration differences occur in the new first stage which is either:

a) a cluster of five 120" diameter, five segment solid rocket motors (Titan IIIC),

b) a cluster of three 156" diameter, three segment SRM's, or

c) a single 260" diameter SRM of 1649" overall length (including nozzle).

The three vehicle classes will be designated herein as SRM/SIVB 120.5, SRM/SIVB 156.3, and SRM/SIVB 260, respectively (see Figure 2).

Each launch vehicle configuration requires a number of subsystems to enable the SRM's to function as a first stage. These include:

1. Thrust vector control systems and associated electronics

2. Roll control system

3. Ignition motors

4. Staging equipment including retro rockets

5. Electrical power sequencing equipment

6. Telemetry and data acquisition systems

7. Emergency detection and abort systems

8. Range safety and destruct equipment, and except for the 260" diameter SRM first stage,

9. Clustering structures.

A forward skirt is required to provide a structural interface with the second (S-IVB) stage and to house first stage subsystems. An aft skirt would provide structural support on the launch pad and a heat shield to protect aft-mounted equipment for vehicle subsystems. S-IVB modifications assumed for use in a solid-boosted configuration are shown in Table 9.

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* Saturn-IB version.

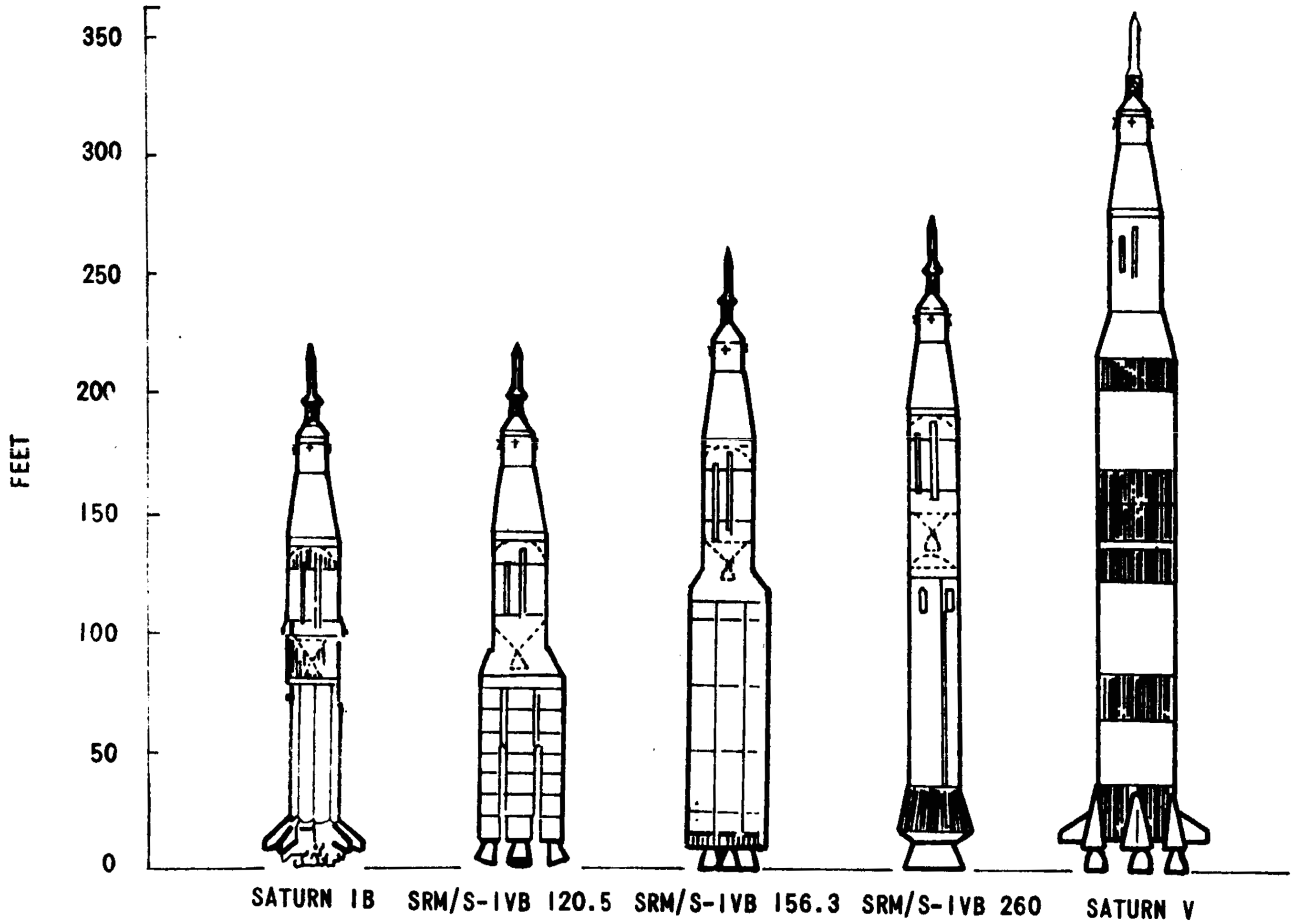


FIGURE 2. SOLID-BOOSTED S-IVB VEHICLE CONFIGURATIONS RELATIVE TO SATURN IB AND SATURN V

TABLE 9. MODIFICATIONS TO THE S-IVB STAGE (S-IB VERSION) FOR USE WITH A SOLID FIRST STAGE

ITEM	WEIGHT CHANGE (#)
REPLACE FORWARD SKIRT WITH S-V/S-IVB FORWARD SKIRT	+122.
REPLACE AFT SKIRT WITH S-V/S-IVB AFT SKIRT	+383.
INCREASE SKIN THICKNESS OF S-IVB LH_2 TANK WALL	+161.
ADD EXTERNAL INSULATION TO AFT SKIRT	+ 72.
TOTAL CHANGE	+738.

TABLE 10. PAYLOAD CAPABILITY OF SOLID-BOOSTED S-IVB VEHICLES

VEHICLE CLASS	FIRST STAGE PROPELLANT LOADING (#)	PAYLOAD DELIVERED TO A 105 N. MI. CIRCULAR ORBIT AT 28.5° INCLINATION (#)
SRM/S-IVB 120.5	$3. \times 10^6$	68,000.
SRM/S-IVB 156.3	3.3×10^6	85,000.
SRM/S-IVB 260.	3.4×10^6	95,000.

NOTE: S-IVB PROPELLANT CAPACITY OF 230,000#, J-2 ENGINE WITH 205,000# VACUUM THRUST HAVE BEEN ASSUMED ABOVE FOR THE STANDARD S-IVB.

TABLE II. COSTS OF ONE TO SIX OPERATIONAL SOLID-BOOSTED S-IVB LAUNCH VEHICLES

VEHICLE CLASS	DEVELOPMENT COST ($ x 10^6)	RECURRING COST PER OPERATIONAL VEHICLE ($ x 10^6)	TOTAL COST FOR X OPERATIONAL VEHICLES ($\$ \times 10^6$)					
			X=1	X=2	X=3	X=4	X=5	X=6
SRM/S-IVB 120.5	250.	45.	295.	340.	385.	430.	475.	520.
SRM/S-IVB 156.3	325.	43.	368.	411.	454.	497.	540.	583.
SRM/S-IVB 260.	400.	40.	440.	480.	520.	560.	600.	640.

NOTE: DEVELOPMENT COSTS INCLUDE R&D TEST FLIGHTS FOR EACH VEHICLE CLASS AS WELL AS LAUNCH FACILITY MODIFICATIONS.

TABLE 12. COST/EFFECTIVENESS OF ONE TO SIX OPERATIONAL SOLID-BOOSTED S-IVB LAUNCH VEHICLES

VEHICLE CLASS	VEHICLE PAYLOAD* (#)	TOTAL COST OF X OPERATIONAL VEHICLES ÷ TOTAL PAYLOAD OF X VEHICLES					
		X=1	X=2	X=3	X=4	X=5	X=6
SRM/S-IVB 120.5	68,000.	4350.	2500.	1900.	1600.	1400.	1300.
SRM/S-IVB 156.3	85,000.	4350.	2400.	1800.	1450.	1300.	1150.
SRM/S-IVB 260.	95,000.	4650.	2500.	1800.	1500.	1250.	1100.

*PAYLOAD INSERTED IN A CIRCULAR ORBIT AT 105 N.MI. ALTITUDE WITH 28.5° ORBITAL INCLINATION.

NOTE: COSTS SHOWN ABOVE ARE IN DOLLARS PER POUND.

TABLE 13. NUMBER OF OPERATIONAL SOLID-BOOSTED S-IVB VEHICLES REQUIRED FOR A LOWER TOTAL COST PER POUND OF PAYLOAD THAN THE S-IB

VEHICLE CLASS	NUMBER OF VEHICLES	
SRM/S-IVB 120.5	14	(13.4)
SRM/S-IVB 156.3	9	(8.85)
SRM/S-IVB 260.	9	(8.16)

NOTE: REFERENCE ORBIT IS CIRCULAR, 105 N.MI. ALTITUDE, WITH A 28.5° INCLINATION.

REFERENCE COST FOR S-IB IS $\$38.0 \times 10^6 \div 40{,}500\# = \$938./\text{LB}$.

Of the candidate SRM's considered, only the 120" diameter motor is operational (Titan IIIC). Static tests have, however, been performed on 156" and 260" diameter motors.

Vehicle performance, as measured by payload capability for a circular orbit of 105 NM altitude with a 28.5° orbital inclination, is shown in Table 10.

The total costs of one to six operational flights, based on development and unit costs given in References 9, 10 are presented in Table 11. Total cost per pound of payload in a 105 NM circular orbit with 28.5° inclination is shown in Table 12. By taking a cost per pound of payload (same orbit) for the Saturn-IB as $\$38.00 \times 10^6 \div 40{,}500\ \# = \$938/\#$, the number of operational solid-boosted S-IVB vehicles required to achieve a lower or equal total cost per pound than the S-IB can be calculated from

$$\frac{C_{NR} + ZC_R}{ZP} \leq 938.$$

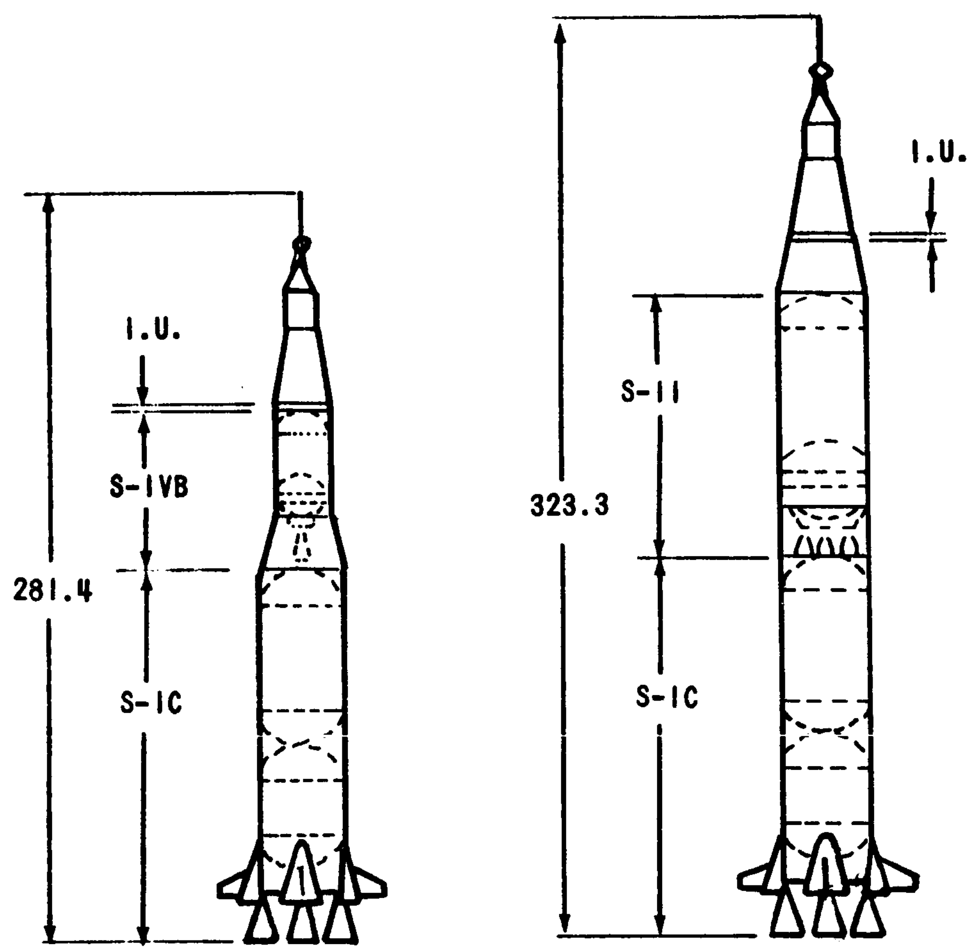
where C_{NR} = nonrecurring cost for a given vehicle class ($)
C_R = recurring cost for a given vehicle class ($)
P = payload deliverable to a 105 NM circular orbit with 28.5° orbital inclination (#)
Z = number of operational launch vehicles required for equal or lower cost/effectiveness ratio than S-IB.

The results, shown in Table 13 indicate that a 260" diameter SRM first stage or the clustered 156" diameter SRM first stage each requires an operational program of at least nine vehicles before a cost saving is effected relative to the S-IB.

5.0 INTERMEDIATE SATURN-V VEHICLES

Two modified Saturn-V vehicles with payload capabilities intermediate between the Saturn-IB and "standard" Saturn-V are discussed in this section. Each employs two of the three S-V stages and retains standard J-2 and F-1 engines. The first configuration, designated SAT-INT-20, employs an SIC lower stage and an SIVB upper stage; the second, designated SAT-INT-21, utilizes an S-II upper stage and an SIC lower stage (see Figure 3). New interstage structures and equipment are required for INT-20, whereas the existing Saturn-V interstage provisions are employed for INT-21.

The payload capability of each vehicle class is shown in Table 14 for several representative orbits. Payloads shown assume a maximum vehicle acceleration of 4.68 g (present limit).



SAT INT-20

SAT INT-21

FIGURE 3. INTERMEDIATE SATURN V VEHICLES

TABLE 14. PAYLOAD CAPABILITY OF INTERMEDIATE SATURN V VEHICLES

CIRCULAR ORBITAL ALTITUDE	100 N. MILES				300 N. MILES			
ORBITAL INCLINATION	34.5°	40.5°	51.5°	90°	34.5°	40.5°	51.5°	90°
SAT INT-20	133.	131.	126.	111.	107.	106.	102.	90.
SAT INT-21	255.	250.	242.	220.	171.	166.	161.	147.

NOTE: PAYLOADS SHOWN ABOVE ARE IN THOUSANDS OF POUNDS.

ASCENT PROFILE IS DIRECT INJECTION TO CIRCULAR ORBIT.

Cost estimates are given in Table 15 for production and launch of one to four operational vehicles. DDT&E costs include design, test, manufacturing and facilities for stages, engines, and launch. Operational costs are based on an assumed production rate for INT-20 or INT-21 of six operational vehicles per year for five years, replacing Saturn-IB production and concurrent with continued Saturn-V production at a rate of six vehicles per year. Test requirements for both vehicles include wind tunnel tests and a check of control instrument locations by establishing vehicle vibration mode shapes and frequencies. It is assumed that one R&D flight will be required for INT-20 and that no R&D flight is required for INT-21 ("2 stage Saturn-V").

Table 16 provides a measure of cost/effectiveness in the form of total cost of X operational vehicles divided by the payload of X vehicles; payloads for several reference orbits are employed. Cost/effectiveness (C/E) ratios below $1000/lb. are obtained for SAT INT-21 in all orbit categories considered for operational programs consisting of as little as one vehicle. For SAT INT-20, two or three operational vehicles are required to achieve C/E ratios below $1000/lb, depending upon the reference orbits chosen.

6.0 DISCUSSION

The launch vehicle configurations described briefly in this memorandum are described extensively in References 1-16. Analyses of maximum dynamic pressure, acceleration, and other parameters pertinent to payload definition and optimization are discussed at length therein. In general the configurations described above have been found to be feasible based on preliminary modification and performance estimates.

Basic cost data for all configurations have been obtained from summaries prepared by Chrysler Space Division (Modified Saturn-IB Vehicles employing strap-on SRM's), Douglas (Solid-Boosted SIVB Vehicles), and Boeing (Intermediate Saturn-V vehicles). Comparisons among the three preceding vehicle categories cannot, therefore, be considered valid without further verification of the detailed assumptions underlying their cost summaries. Such costs, while hardly to be considered definitive, are nevertheless the best available at this writing.

The measure of cost/effectiveness employed in this memorandum* was chosen in anticipation of missions which effectively utilize the entire payload of a given vehicle, excluding design margins. Obviously missions which do not fully utilize payload capability must be assessed with different criteria. Current experience with AAP mission planning, however, indicates that long duration missions, particularly a projected one year mission, can easily utilize entire vehicle payloads.

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* Total cost (excluding items attributable to payload) of X operational vehicles divided by the combined payload of X vehicles of the same class.

TABLE 15. COST OF ONE TO FOUR OPERATIONAL INTERMEDIATE SATURN V LAUNCH VEHICLES

VEHICLE CLASS	NONRECURRING COSTS ($ x 10^6)		RECURRING COST PER OPERATIONAL VEHICLE ($ x 10^6)	TOTAL COST OF X OPERATIONAL VEHICLES ($ x 10^6)			
	DDT&E	R&D FLIGHT*		X=1	X=2	X=3	X=4
INT-20	29.3	61.0	61.0	151.3	212.3	273.3	334.3
INT-21	32.3	0.0	89.2	121.5	210.7	229.9	389.1

*ONE R&D FLIGHT FOR SAT INT-20; NONE FOR SAT INT-21.

TABLE 16. COST/EFFECTIVENESS OF INTERMEDIATE SATURN V VEHICLES

VEHICLE CLASS	CIRCULAR ORBITAL PARAMETERS		TOTAL COST OF X OPERATIONAL VEHICLES ÷ TOTAL PAYLOAD OF X VEHICLES			
	ALTITUDE (N. MILES)	INCLINATION (°)	X = 1	X = 2	X = 3	X = 4
SAT INT-20	100.	34.5	1140.	800.	685.	630.
		40.5	1160.	811.	695.	639.
		51.5	1200.	843.	722.	664.
		90.0	1370.	957.	821.	753.
	300.	34.5	1420.	993	850.	783.
		40.5	1430.	1000.	859.	790.
		51.5	1480.	1040.	894.	822.
		90.0	1690.	1180.	1000.	930.
SAT INT-21	100	34.5	477.	395.	392.	381.
		40.5	487.	403.	400.	389.
		51.5	502	416.	414.	402.
		90.0	552.	457	455.	442.
	300.	34.5	711.	589.	584,	569.
		40.5	733.	606.	602.	586.
		51.5	755.	625.	622.	604.
		90.0	828.	685.	680.	662.

NOTE: COST/EFFECTIVENESS UNITS ABOVE ARE $/LB.

The number of operational vehicles required to become competitive with the present Saturn I-B in terms of cost/effectiveness is a useful parameter in assessing the magnitude of program commitment required to justify the development of modified Saturn launch vehicles. Table 17 indicates a comparison of the vehicle classes considered in this memorandum. The lowest nonrecurring cost identified is that of the SAT INT 21 ($\$32.3 \times 10^6$); The lowest recurring cost, with the exception of the S-IB baseline ($\$38.0 \times 10^6$) is that of SRM/S-IVB-260. The highest payload for a low altitude, low inclination orbit is that of SAT INT 21 (255,000#). SAT INT 21 also requires only one operational flight to achieve a lower cost/effectiveness than that of a Saturn I-B.

Among the S-IB "strap-on" configurations the greatest payload (106,000#) and least number of operational flights required for a c/e competitive with that of Saturn-IB occurs for S-IB-11.7A. Among the vehicle classes considered in this memorandum, the least efficient, in terms of numbers of operational vehicles required to compete with Saturn I-B on a cost/effectiveness basis, is S-IB-14 (Minuteman Strap-ons).

1022-DJB-mef

D. J. Belz

TABLE 17 - COMPARISON OF VEHICLE CLASSES FOR LOW ALTITUDE, LOW INCLINATION MISSIONS

VEHICLE CLASS	COST ($\$ \times 10^6$)		VEHICLE PAYLOAD* (#)	NO. OF OPERATIONAL VEHICLES REQUIRED FOR COST/EFFECTIVENESS EQUAL TO OR LOWER THAN THAT OF SATURN IB
	NONRECURRING	RECURRING		
S-IB BASELINE	—	38.0	37,500	—
S-IB - 11.5	212.46	46.70	78,400	7
S-IB - 11.5A	240.89	47.40	87,900	6
S-IB - 11.7A	248.84	48.59	106,000	5
S-IB - 13.7	207.44	44.44	80,500	6
S-IB - 14	176.43	41.39	50,600	19
SRM/SIVB 120.5	250.	45.	68,000	14
SRM/SIVB - 156.3	325.	43.	85,000	9
SRM/SIVB - 260	400.	40.	95,000	9
SAT INT 20	90.3	61.	133,000	2
SAT INT 21	32.3	89.2	255,000	1

*PAYLOADS FOR SIB BASELINE AND S-IB-11.5 THROUGH S-IB-14 ARE BASED ON CIRCULAR ORBITS WITH 100 N. MI. ALTITUDE AND 33° INCLINATION.

PAYLOADS FOR SRM/SIVB 120.5 THROUGH SRM/SIVB-260 ARE BASED ON CIRCULAR ORBITS WITH 105. N. MI. ALTITUDE AND 28.5° INCLINATION.
SAT INT 20 AND SAT INT 21 PAYLOADS ARE BASED ON CIRCULAR ORBITS WITH 100 N. MILE ALTITUDE AND 34.5° INCLINATION.

REFERENCES

1. Saturn-IB Family/Configuration and Performance Data, Chrysler Corporation Space Division, November 1966.

2. Saturn Improvement Studies, Presentation at NASA Headquarters by MSFC, November 21, 1966.

3. B. H. Lightfoot, Saturn-IB/Zero Stage Study Report, Chrysler Corporation Space Division, December 31, 1965.

4. Saturn-IB Improvement Study, Phase II Mid-Term Presentation, Chrysler Corporation Space Division, May 18, 1966.

5. Saturn-IB Improvement Study, Phase II Final Presentation, Chrysler Corporation Space Division, May 18, 1966.

6. Saturn-IB Improvement Study, Phase II Final Report, Volume 1-Summary, Chrysler Corporation Space Division, October 5, 1966.

7. Phase II Study of Launch Facilities for Improved Saturns, MLV-Saturn-IB's, and V's, Presentation by the Martin Company at KSC, undated.

8. Saturn Improvement Studies, NASA/MSFC, 1964.

9. Saturn-IB Improvement Study (Solid First Stage), Phase II Final Summary Report, Douglas Missile & Space Systems Division, March 30, 1966.

10. R.P. Dawson, The Solid Boosted Saturn S-IVB Stage as a Low Cost Expendable System (Draft), Douglas Aircraft Company, Huntington Beach, California, undated.

11. Intermediate Payload Launch Vehicles: Mission Analysis, Boeing Space Division, Huntsville, Alabama, February 14, 1967.

12. Final Report - Studies of Improved Saturn-V Vehicles and Intermediate Payload Vehicles, Summary, Boeing Space Division, October 1966.

13. J. E. Martin, Saturn-V Growth and Flexibility, Boeing Space Division, undated.

14. Research Activities: Summary Report, Boeing Space Division, January 15, 1967.

15. Studies of Improved Saturn-V Vehicles and Intermediate Saturn Vehicles, Volume 1 - Summary Report, North American Aviation, Space & Information Systems Division, October 1966.

16. Studies of Improved Saturn-V Vehicles and Intermediate Payload Vehicles - Final Review, Boeing Space Division, October 1966.

REFERENCES (continued)

17. H. S. London, Trip Report - Chrysler Saturn-IB Improvements Study - Case 130, Bellcomm Memorandum for File, March 26. 1965.

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